EFFICIENT PREPARATION OF A VERSATILE CHIRAL SYNTON FOR 1,2-DIAMINES VIA THE Fe(III)-CATALYZED DIASTEREOSELECTIVE OXIDATION OF 2-IMIDAZOLONE AND ITS APPLICATION

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Abstract – The efficient and predominant preparation of (4S,5S)-4,5-dimethoxy-2-imidazolidinone (DMIm) was established via the Fe(III)-catalyzed diastereoselective oxidation of 1-[(1S,2R)-2-exo-alkoxyapocamphanecarbonyl]-2-imidazolone with aqueous H$_2$O$_2$ up to 94% d.e., both of which were easily purified by column chromatography, followed by simple and convenient conversions. The obtained N-tosyl-(4S,5S)-DMIm proved to be a versatile chiral synthon for 1,2-diamines by the synthesis of (1S,2S)-1,2-diamino-1-(4-fluorophenyl)butane derivative, whose platinum complex showed potent antitumor activity.

The 1,2-diamine framework is an important component of a substantial number of compounds that are of biological and medicinal importance, as well as for efficient chiral ligands for use in asymmetric reaction systems that include derivatives such as imidazolines and Schiff bases. Hitherto, there have been a number of methodologies for the synthesis of chiral 1,2-diamines such as derivatization from amino acids, substitutional induction of nitrogen nucleophiles to haloalkanes, conjugate addition of nitrogen nucleophiles to nitroalkenes and aziridines, diamination of 1,2-diols, and the coupling reaction of imines. Most of these methodologies, however, are primarily for the construction of a specific side chain structure and/or a stereocenter. Therefore, a versatile method for the chiral syntheses of various types of $C_2$-symmetric and unsymmetric 1,2-diamines is still needed.

* Dedicated to Professor Dr. Isao Kuwajima on the occasion of his 77th birthday
We previously reported that both enantiomers of optically active trans-4,5-dimethoxy-2-imidazolidinone (DMIm, 2) were available from the 5-membered heterocycle, 1,3-diacetyl-2-imidazolone (1), which functions as a versatile chiral synthon for the construction of various types of chiral 1,2-diamines (5), including the stepwise and stereospecific conversion of two hemiamineether moieties to other substituents followed by ring-cleavage (Scheme 1).

Recently, we discovered an alternative and effective method for the preparation of both enantiomers of DMIm using the Fe(III) (FeCl(dipic)(H₂O)₂)-catalyzed oxidation of achiral 2-imidazolone by H₂O₂-urea followed by the optical resolution of the N-arylsulfonyl derivatives using (1S,2R)-2-exo-methoxyapocamphanecarboxylic acid (MAC acid). This synthetic methodology avoided the use of bromine, which is harmful and difficult to handle, and presented a more practical and facile pathway to optical resolution compared with the previous one.

Although the preparation of both enantiomers of DMIm is useful for the construction of chemical libraries in the field of medicinal chemistry, a predominant supply of one of the enantiomers of DMIm would also be desirable for a versatile preparation of chiral 1,2-diamines with a particular configuration.

In our previous work, attempts to prepare chiral DMIm by diastereomeric addition to chiral 2-imidazolones were insufficient, because of the low regioselectivity of the addition reactions. Recent results concerning the Fe(III)-catalyzed oxidation of 2-imidazolone by H₂O₂ motivated us to apply this methodology in a diastereoselective manner for the practical synthesis of chiral DMIm.

Herein, we report an efficient method for the predominant preparation of (4S,5S)-4,5-dimethoxy-2-imidazolidinone ((4S,5S)-DMIm) via the Fe(III)-catalyzed diastereoselective oxidation of 1-[(1S,2R)-2-exo-methoxyapocamphanecarbonyl]-2-imidazolone (6a) with aqueous H₂O₂ or H₂O₂-urea followed by simple conversions. A biologically interesting synthetic application of (4S,5S)-DMIm for chiral 1,2-diamine is also described.

We first examined the reactivity and diastereoselectivity of the Fe(III) complex-catalyzed oxidation of chiral 2-imidazolone, 1-[(1S,2R)-2-exo-methoxyapocamphanecarbonyl]-2-imidazolone (6a) (Table 1, entries 1-6). Under the same reaction conditions detailed in a previous report, a 70% yield of the diastereomeric mixture of trans-4-methoxy-5-hydroxy-2-imidazolidinone (7a and 8a) was obtained with moderate diastereoselectivity (entry 1). Based on the monitoring of the reaction mixture via TLC, we
decided that the addition of H$_2$O$_2$-urea should be divided. With three additions, each of a 0.5 equivalent, a slightly higher chemical yield was achieved (76%; entry 2). The higher concentration led to a much faster reaction with a slight decrease in diastereoselectivities (entries 3 and 4). Further addition of H$_2$O$_2$-urea (0.5 eq; total 2 eq) resulted in an 82% yield (entry 5). Lower reaction temperatures such as 0 °C retarded the reaction, given an acceptable reaction time, and resulted in an 80% yield with a 52% d.e. (entry 6). PAC-2-imidazolone had a bulkier $n$-propoxy moiety compared with the methoxy group in the chiral auxiliary, and showed a lower reactivity that resulted in a 27% yield and a d.e. value similar to that of MAC-2-imidazolone (entry 7).

**Table 1.** The Fe(III)-catalyzed oxidation of 1-[(1S,2R)-2-exo-alkoxyapocamphanecarbonyl]-2-imidazolone by hydrogen peroxide in the presence of MeC(OMe)$_3$

<table>
<thead>
<tr>
<th>Entry</th>
<th>R</th>
<th>Conc. (M)$^b$</th>
<th>eq. of H$_2$O$_2$-urea</th>
<th>Temp (°C)</th>
<th>Method$^c$</th>
<th>Time (h)</th>
<th>Yield (%)$^f$</th>
<th>%d.e.$^g$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Me</td>
<td>0.05</td>
<td>1.5</td>
<td>25</td>
<td>A</td>
<td>3</td>
<td>70</td>
<td>49</td>
</tr>
<tr>
<td>2</td>
<td>Me</td>
<td>0.05</td>
<td>1.5</td>
<td>25</td>
<td>B</td>
<td>2.5</td>
<td>76</td>
<td>50</td>
</tr>
<tr>
<td>3</td>
<td>Me</td>
<td>0.1</td>
<td>1.5</td>
<td>25</td>
<td>B</td>
<td>2</td>
<td>77</td>
<td>46</td>
</tr>
<tr>
<td>4</td>
<td>Me</td>
<td>0.2</td>
<td>1.5</td>
<td>25</td>
<td>C</td>
<td>1</td>
<td>77</td>
<td>42</td>
</tr>
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<td>5</td>
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<td>0.2</td>
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<td>25</td>
<td>C</td>
<td>1.3</td>
<td>82</td>
<td>45</td>
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<td>6</td>
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<td>0.2</td>
<td>2</td>
<td>0</td>
<td>B</td>
<td>3.5</td>
<td>80</td>
<td>52</td>
</tr>
<tr>
<td>7</td>
<td>Pr</td>
<td>0.2</td>
<td>2</td>
<td>0</td>
<td>B</td>
<td>5</td>
<td>27$^f$</td>
<td>51</td>
</tr>
</tbody>
</table>

$^a$ Reactions were carried out in the mixture of trimethyl orthoacetate (1.6 mL) and CH$_2$Cl$_2$ (3.7 mL) with 6a/b (0.265 mmol), FeCl(dipic)(H$_2$O)$_2$ (7.7 mg, 0.1 eq), i-Pr$_2$NH•HCl (3.6 mg, 0.1 eq) and H$_2$O$_2$-urea (37.4 mg, 1.5 eq) at 25 °C except for other designated conditions. For detail, see ref. 7.

$^b$ Concentration of substrate in the reaction system. Thus, volume of the solvents were changed.

$^c$ Method A: H$_2$O$_2$-urea was added to the reaction mixture all at once; method B: 0.5 eq of H$_2$O$_2$-urea was added to the reaction mixture every 30 minutes; method C: 0.5 eq of H$_2$O$_2$-urea was added to the reaction mixture every 20 minutes;

$^d$ Isolated yields.

$^e$ Determined by $^1$H NMR.

$^f$ 26% of starting material was recovered.

The obtained diastereomeric mixture of trans-4-methoxy-5-hydroxy-2-imidazolidinone ($7a$+$8a$; $7a$/$8a$ = 76/24) was regioselectively acetylated, and the subsequent N-tosylation yielded a mixture of 10 and 11, which was easily separable using SiO$_2$ chromatography. The MAC group of the major product 10 was
then reductively removed via a combination of LiBH$_4$ and MeOH (1:2), and a 4-hydroxy group of 12 was smoothly converted to a methoxy moiety with a full retention of configuration to yield N-tosyl-(4S,5S)-DMIm (13) (Scheme 2).

We also tested a similar Fe(III)-catalyzed oxidation of chiral 2-imidazolones (6a,b) in the presence of t-BuOH, in place of MeC(OMe)$_3$ (Table 2). In accordance with Beller’s procedure,$^8$ the treatment of a chiral 2-imidazolone with aqueous H$_2$O$_2$ in the presence of a catalytic amount of FeCl$_3$•6H$_2$O, dipicolinic acid, diisopropylamine, and powdered MS4A, and using a t-BuOH/CH$_2$Cl$_2$ (1:1) mixture as a solvent, yielded trans-4-tert-butoxy-5-hydroxy-2-imidazolidinones (14a/b, 15a/b), both of which were simply separated via SiO$_2$ chromatography. The FeCl(dipic)(H$_2$O)$_2$-catalyzed oxidation of 6a with aqueous H$_2$O$_2$ gave results similar to those of the FeCl$_3$-catalyzed reaction (entries 1 and 3). The use of aqueous H$_2$O$_2$ induced a higher diastereoselectivity compared with that induced by using H$_2$O$_2$ urea as an oxidant, and a 94% d.e. was achieved when using 1-PAC-2-imidazolone (6b) as the substrate.$^{11}$

Optically pure (4S,5S)-trans-4-tert-butoxy-5-hydroxy-2-imidazolidinone (14a) was almost quantitatively converted to the corresponding (4S,5S)-trans-4-methoxy-5-hydroxy-2-imidazolidinone (7a), which led to N-tosyl-(4S,5S)-DMIm (13) in the way similar to the reaction shown in Scheme 2 (Scheme 3).$^{12}$

The versatility of the obtained N-tosyl-(4S,5S)-DMIm (13) was demonstrated by the chiral synthesis of a (1S,2S)-1,2-diamino-1-(4-fluorophenyl)butane derivative (21) with a platinum complex (22) that showed potent antitumor activity.$^{13}$ (Scheme 4). Thus, N-tosyl-(4S,5S)-DMIm (13) was treated with 4-fluorophenylcuprate in the presence of BF$_3$•OEt$_2$ at -30 °C for 3 hours, resulting in the regioselective replacement of the 4-methoxy moiety with a 4-fluorophenyl group with perfect retention of configuration and a 19% recovery of 13. A subsequent 3-acetylation followed by the removal of the tosyl moiety under UV-irradiation in the presence of sodium cyanoborohydride and anisole$^5$ gave a 1-acetyl-4-methoxy derivative (18). A treatment of 18 with ethylcuprate in the presence of BF$_3$•OEt$_2$ at -30 °C for 3 hours
Table 2. The Fe(III)-catalyzed oxidation of 1-[(1S,2R)-2-exo-alkoxyapocamphanecarbonyl]-2-imidazolone by hydrogen peroxide in the presence of t-BuOH

<table>
<thead>
<tr>
<th>Entry</th>
<th>R</th>
<th>Fe(III) complex</th>
<th>H₂O₂</th>
<th>Yield (%)&lt;sup&gt;c&lt;/sup&gt;</th>
<th>%d.e.&lt;sup&gt;d&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>1&lt;sup&gt;b&lt;/sup&gt;</td>
<td>Me</td>
<td>FeCl₂·6H₂O (0.1) dipicolinic acid (0.1)</td>
<td>30% H₂O₂aq</td>
<td>84</td>
<td>63</td>
</tr>
<tr>
<td>2&lt;sup&gt;b&lt;/sup&gt;</td>
<td>Pr</td>
<td>FeCl₂·6H₂O (0.1) dipicolinic acid (0.1)</td>
<td>30% H₂O₂aq</td>
<td>74</td>
<td>94</td>
</tr>
<tr>
<td>3&lt;sup&gt;b&lt;/sup&gt;</td>
<td>Me</td>
<td>FeCl₂(dipic)(H₂O)₂ (0.1)  i-Pr₂NH+HCl (0.1)</td>
<td>30% H₂O₂aq</td>
<td>88</td>
<td>63</td>
</tr>
<tr>
<td>4</td>
<td>Me</td>
<td>FeCl₂(dipic)(H₂O)₂ (0.1)  i-Pr₂NH+HCl (0.1)</td>
<td>H₂O₂-urea</td>
<td>85</td>
<td>56</td>
</tr>
<tr>
<td>5</td>
<td>Pr</td>
<td>FeCl₂(dipic)(H₂O)₂ (0.1)  i-Pr₂NH+HCl (0.1)</td>
<td>H₂O₂-urea</td>
<td>35</td>
<td>78</td>
</tr>
</tbody>
</table>

<sup>a</sup> For reaction conditions, see ref. 9.
<sup>b</sup> MS4A (powdered) was added to the reaction mixture. 101
<sup>c</sup> Isolated yields.
<sup>d</sup> Determined by 1H NMR.

Scheme 3

gave a 54% yield of trans-4-ethyl-5-(4-fluorophenyl)-2-imidazolidinone (19), accompanied by a cis-adduct (9%)<sup>14</sup> and the recovered 18 (26%). Smoothtosylation and deacetylation followed by hydrolytic ring-opening with Ba(OH)₂·8H₂O in a mixture of EtOH, H₂O and DMSO (5:1:1), with subsequent N-Boc protection, afforded the (3S,4S)-N,N'-diprotected diamine 21 in an 80% yield in 2 steps, and both of the protecting groups could be easily removed under acidic condition (TFA for the Boc group) and reductive condition (sodium naphthalenide for tosyl group), respectively.
In conclusion, we established an efficient method for the predominant preparation of 
(4S,5S)-4,5-dimethoxy-2-imidazolidinone (DMIm) via the Fe(III)-catalyzed diastereoselective oxidation of chiral 2-imidazolone, 1-[(1S,2R)-2-exo-alkoxyapocamphanecarbonyl]-2-imidazolone, by aqueous H₂O₂ up to 94% d.e., with facile purification accomplished via column chromatography, followed by simple and convenient conversions. The obtained N-tosyl-(4S,5S)-DMIm (13) proved to be a versatile chiral synthon for 1,2-diamines; the synthesis of a (1S,2S)-1,2-diamino-1-(4-fluorophenyl)butane derivative (21) had a platinum complex that showed potent antitumor activity. Mechanistic studies for the Fe(III)-catalyzed oxidation of 2-imidazolone and further synthetic application using chiral DMIm are underway.

ACKNOWLEDGEMENTS

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REFERENCES AND NOTES


7. General procedure for the FeCl(dipic)(H\(_2\)O)\(_2\)-catalyzed oxidation of 1-[(1S,2R)-2-exo-alkoxyapocamphane-carbonyl]-2-imidazolone by hydrogen peroxide in the presence of MeC(OMe)\(_3\): The mixture of FeCl(dipic)(H\(_2\)O)\(_2\) (7.7 mg, 0.1 eq; the granule was pulverized by microspatula) and \(\text{i-Pr}_2\text{NH}\cdot\text{HCl}\) (3.6 mg, 0.1 eq) in CH\(_2\)Cl\(_2\) (2.3 mL) was stirred at 25 °C for 30 min and 2-imidazolone (0.2648 mmol) in CH\(_2\)Cl\(_2\) (1.4 mL) was added to the mixture. After pouring MeC(OMe)\(_3\) (1.6 mL) into the mixture at 0 °C was added H\(_2\)O\(_2\)-urea (37.4 mg, 1.5 eq) at once with stirring at 25 °C. After the consumption of 2-imidazolone (monitored by TLC), the reaction mixture was passed through a SiO\(_2\) pad to remove the iron species and the filtrate was concentrated in vacuo. The residue was purified by chromatography on SiO\(_2\) (hexane/EtOAc; 9/1 to 5/5) to yield the 4-methoxy-5-hydroxy-2-imidazolidinones.


9. General procedure for the Fe(III)-catalyzed oxidation of 1-[(1S,2R)-2-exo-alkoxyapocamphane-carbonyl]-2-imidazolone by hydrogen peroxide in the presence of \(\text{t-BuOH}\) (Table 2, entries 1 and 2): To a suspension of FeCl\(_3\)•6H\(_2\)O (10.2 mg, 0.1 eq) and dipicolinic acid (6.3 mg, 0.1 eq) in CH\(_2\)Cl\(_2\) (0.5 mL) and \(\text{t-BuOH}\) (0.5 mL) was added \(\text{i-Pr}_2\text{NH}\) (10.7 \(\mu\)L, 0.2 eq) and the suspension was stirred at 25 °C for 30 min. After the addition of 1-[(1S,2R)-2-exo-alkoxyapocamphane-carbonyl]-2-imidazolone (6a,b) (0.38 mmol), powdered molecular sieves 4A (378 mg), CH\(_2\)Cl\(_2\) (2.9 mL) and \(\text{t-BuOH}\) (2.9 mL) to the catalyst mixture with stirring for 10 min at 25 °C, an aqueous H\(_2\)O\(_2\) solution (30%; 77.4 \(\mu\)L, 2 eq) in \(\text{t-BuOH}\) (0.7 mL) was added to the reaction mixture over 1 h using a syringe pump at 0 °C followed by stirring for 30 min at 0 °C. After the consumption of 2-imidazolone (monitored by TLC), the reaction mixture was passed through a SiO\(_2\) pad (EtOAc as eluent) to quench the reaction and the eluent was then evaporated in vacuo followed by flash column
chromatography on silica gel (CH$_2$Cl$_2$/EtOAc; 95/5 to 85/15) to yield (4S,5S)-1-[(1S,2R)-2-exo-alkoxyapocamphanecarbonyl]-4-tert-butoxy-5-hydroxy-2-imidazolidinone (14a,b) predominantly, along with the corresponding (4R,5R)-isomer (15a,b).

10. From the preliminary finding as follows: the treatment of N-tosyl-2-imidazolone (23) with aqueous hydrogen peroxide solution (30%) in the presence of FeCl$_3$•6H$_2$O, dipicolinic acid and diisopropylamine using a $t$-BuOH/CH$_2$Cl$_2$ (1:1) mixture as a solvent yielded 4-tert-butoxy-5-hydroxy- (24) and 4,5-dihydroxy-2-imidazolidinone (25). The prior addition of powdered MS4A to the reaction mixture before the addition of 30% H$_2$O$_2$ aq dramatically decreased the 4,5-dihydroxy adduct, and increased the 4-tert-butoxy-5-hydroxy-product (Scheme 5).

11. The observed stereoselectivity is consistent with the postulation that iron oxide species approach from the less hindered face of 2-imidazolone to form epoxide 26 followed by the an anti-periplanar attack of alkoxy group to give the (4S,5S)-product predominantly (Scheme 6).

12. Absolute configuration of 14a was determined by the X-ray crystallographical analysis of compound 29, derived from 14a (Scheme 7), as depicted in Figure 1. The X-ray crystallographical data of 29 (CCDC number: 1016706) can be obtained free of charge from The Cambridge Crystallographic Data Centre via www.ccdc.cam.ac.uk/data_request/cif.

14. We speculate that the attack of ethylcuprate toward the acyliminium ion intermediate was not effectively controlled by the vicinal 4-fluorophenyl group to form *cis*-adduct as a minor product.